



University of Colorado
Boulder

Biogenic Sulfuric Acid-Resistant Geopolymer Cements

PI: Wil V. Srubar III, PhD, University of Colorado Boulder
Co-PI: Claire White, PhD, Princeton University

Mohammad Matar, Christine Pu, Xu Chen, Kai Gong, Yige Zhang, Halie Brimelow

Solving biogenic acid-induced concrete corrosion, cement-related CO₂ emissions, and life-cycle cost with performance-enhanced alkali-activated metakaolin (geopolymer) cements

Sewer Systems in the United States



SOB



Problem: Biogenic Sulfuric Acid Degradation of OPC Concrete
via Microbial-Induced Concrete Corrosion

\$13.8B

Per Year on MICC

Proposed Solution: Low-Calcium Alkali-Activated Cement
(i.e., Geopolymer) Concrete

Sewer Systems in the United States

Conventional Materials Used in Sewer Infrastructure

Metal



- Mechanically durable
- High cost and subject to corrosion

Polymer



- Corrosion resistance
- Not for extreme temperature

Clay



- Brittle and low strength
- High chemical resistance

Concrete



- High strength
- Subject to corrosion

Our Solution:

Alkali-Activated
Metakaolin
(i.e., Geopolymer)
Coating

ARPA-E Project Objectives:

To engineer a geopolymer cement that exhibits **80% reductions in steady-state biodeterioration rates** compared to OPC concrete (**from ~5 mm year to ~1 mm year**), which will extend the service life of concrete sewer infrastructure **~5X (250 Years)** and will yield reductions in total life cycle environmental (i.e., embodied energy and embodied carbon) costs of mitigating biogenic sulfuric acid degradation by **75%**.

The Team

University of Colorado Boulder

PI: Wil V. Srubar III, Ph.D.



- ▶ Specializes in integrating biology, polymer science, and cement chemistry for innovative, responsive material technologies; Previous NSF Award on Acid Resistant Geopolymers
- ▶ Researchers: Xu Chen, Mohammad Matar, Halie Brimelow

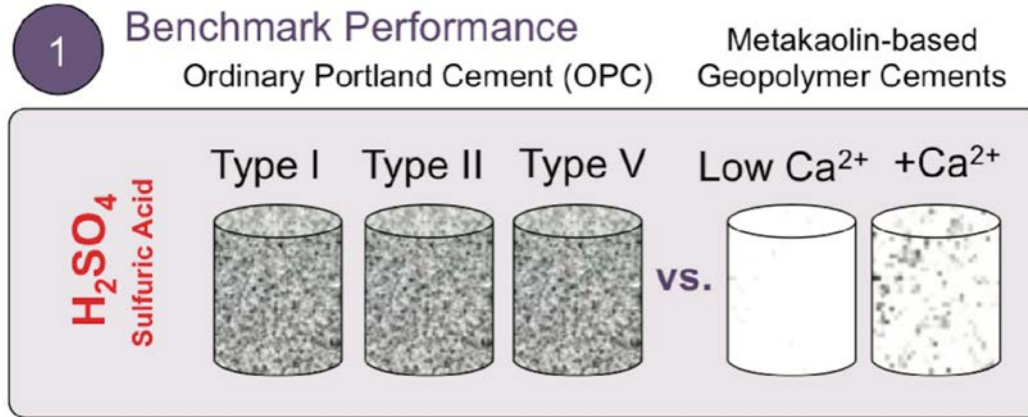
Princeton University

Co-PI: Claire E. White, Ph.D.

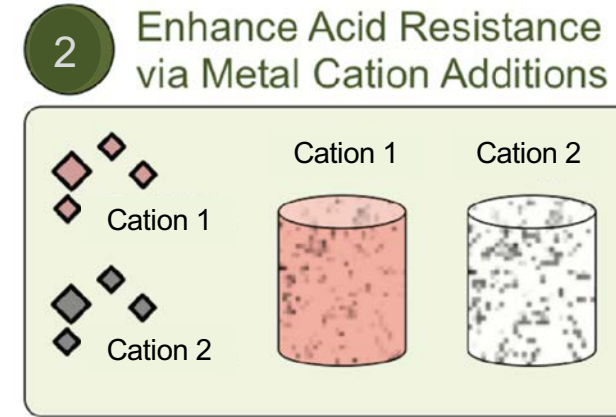


- ▶ Specializes in the complex and heterogeneous sub-micron structures and processes in conventional and alternative cements using a combined simulation-experiment approach
- ▶ Researchers: Kai Gong, Christine Pu, Yige Zhang

Project Objectives



- ▶ **Goal #1:**
- ▶ Establish benchmarks for sulfuric acid resistance and desirable mechanical properties; and
- ▶ Demonstrate superiority of low-calcium geopolymer binders for sulfuric acid resistance

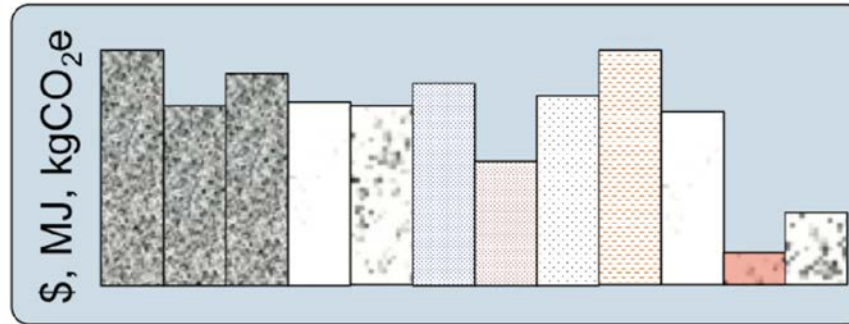


- ▶ **Goal #2:**
- ▶ Maximize sulfuric acid resistance through novel cation additives; strongly bound cations that stabilize geopolymer framework



Project Objectives

3 Compute Life Cycle Economic & Environmental Costs



- ▶ **Goal #3:** Substantiate improved economic and environmental viability through lifecycle cost analysis and lifecycle assessment

Results: Benchmarking

OPC Samples

Mix	>15 MPa*	<40%	<24 hours
	Compressive strength	Porosity	Setting time
I/II – w/c=0.4	Pass	Pass	Pass
I/II – w/c=0.5	Pass	Pass	Pass
II/V – w/c=0.4	Pass	Pass	Pass
II/V – w/c=0.5	Pass	Pass	Pass

*14 Days



Formulation passed all characterization tests

Formulation failed one or more characterization test

Results: Benchmarking

OPC Samples

	>15 MPa*	<40%	<24 hours
Mix	Compressive strength	Porosity	Setting time
I/II – w/c=0.4	Pass	Pass	Pass
I/II – w/c=0.5	Pass	Pass	Pass
II/V – w/c=0.4	Pass	Pass	Pass
II/V – w/c=0.5	Pass	Pass	Pass

*14 Days



Formulation passed all characterization tests
 Formulation failed one or more characterization test

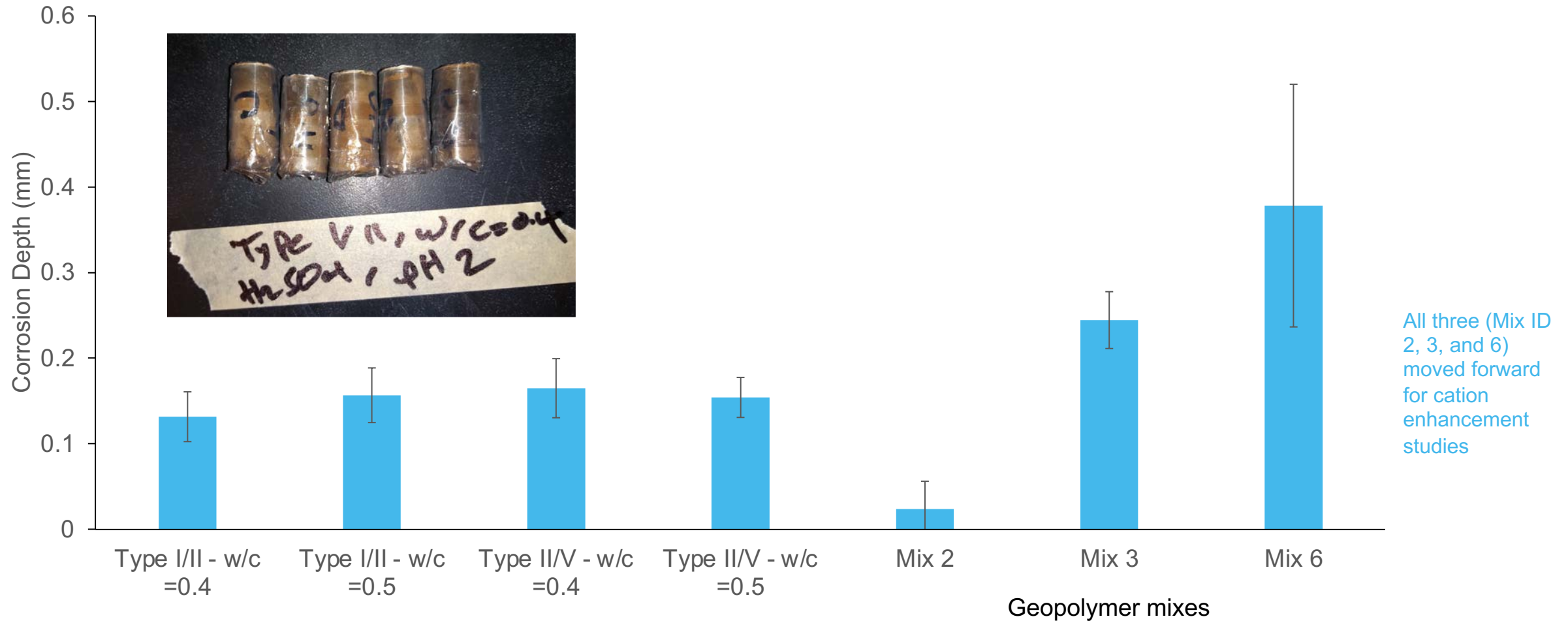
Geopolymers

	>15 MPa	<40%	<24 hours
Mix	Compressive strength	Porosity	Setting time
1	NG	NG	Pass
2	Pass	Pass	Pass
3	Pass	Pass	Pass
4	Pass	Pass	Pass
5	NG	-	NG
6	Pass	Pass	Pass

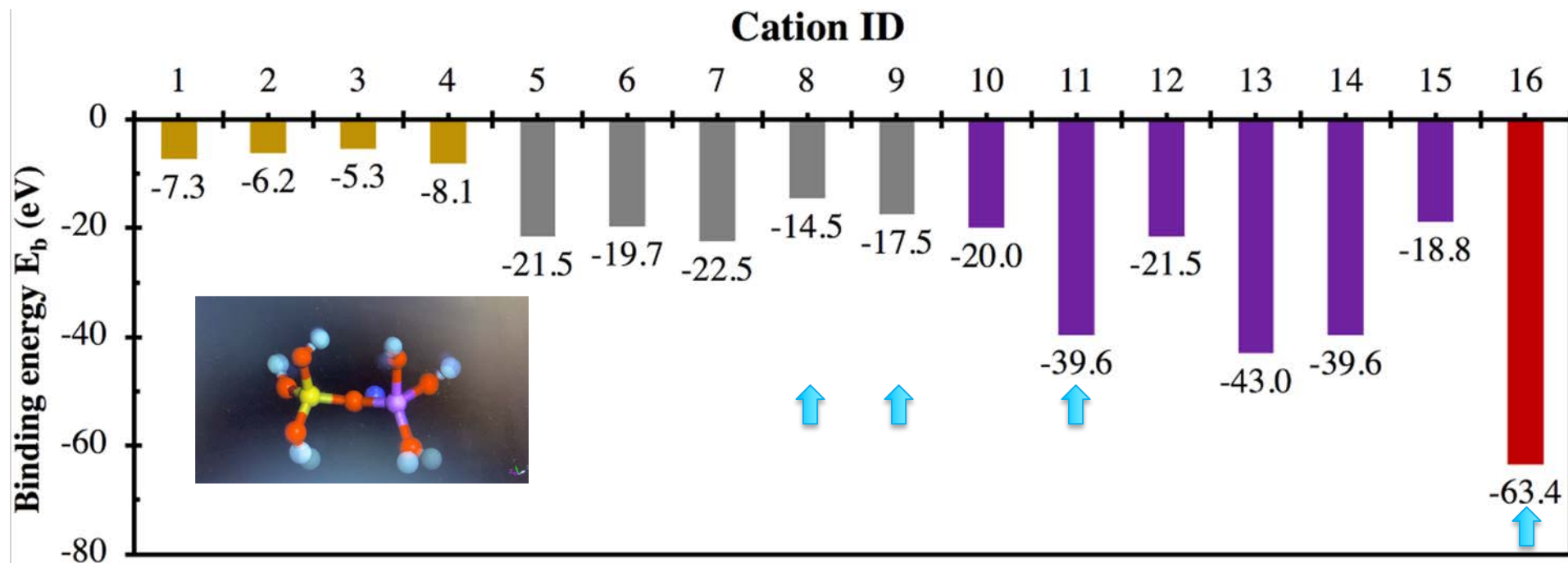
← = Selected for Further Study Based on Performance and Cost Considerations

Results: Benchmarking

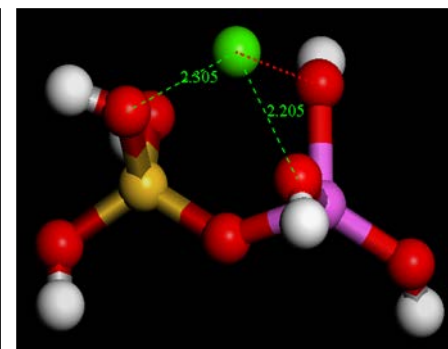
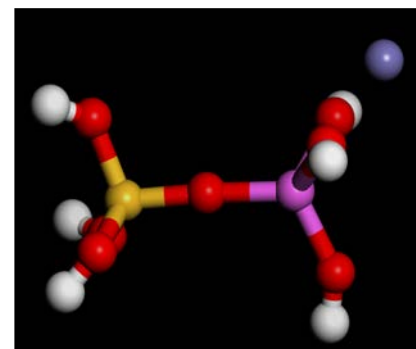
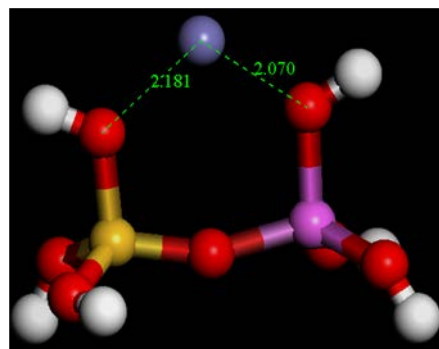
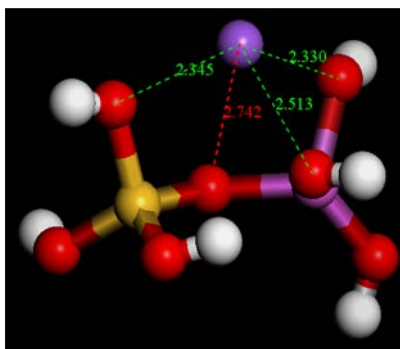
H₂SO₄ Exposure: Sample Corrosion Depth @ 7 Days



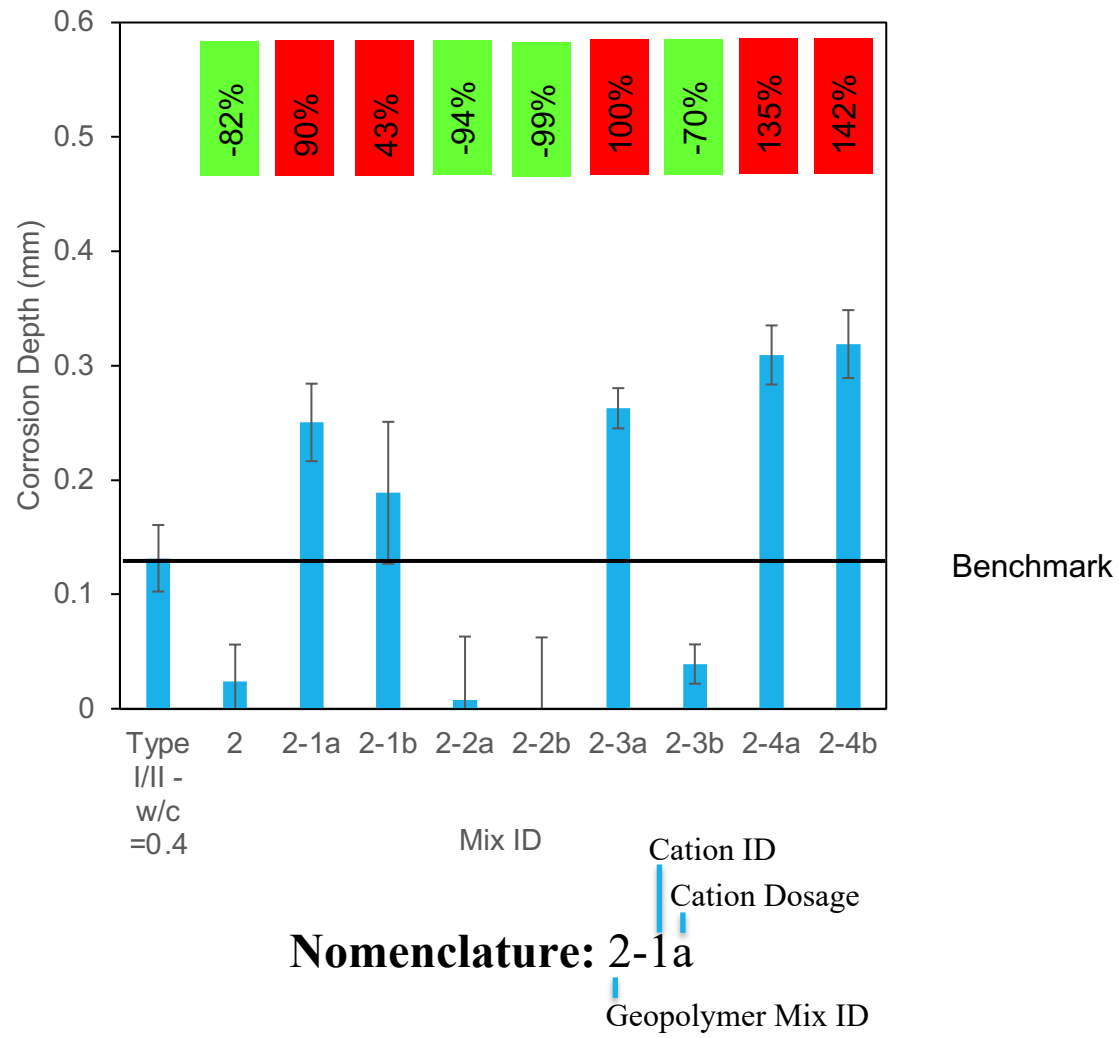
Results: Cation Binding Energies



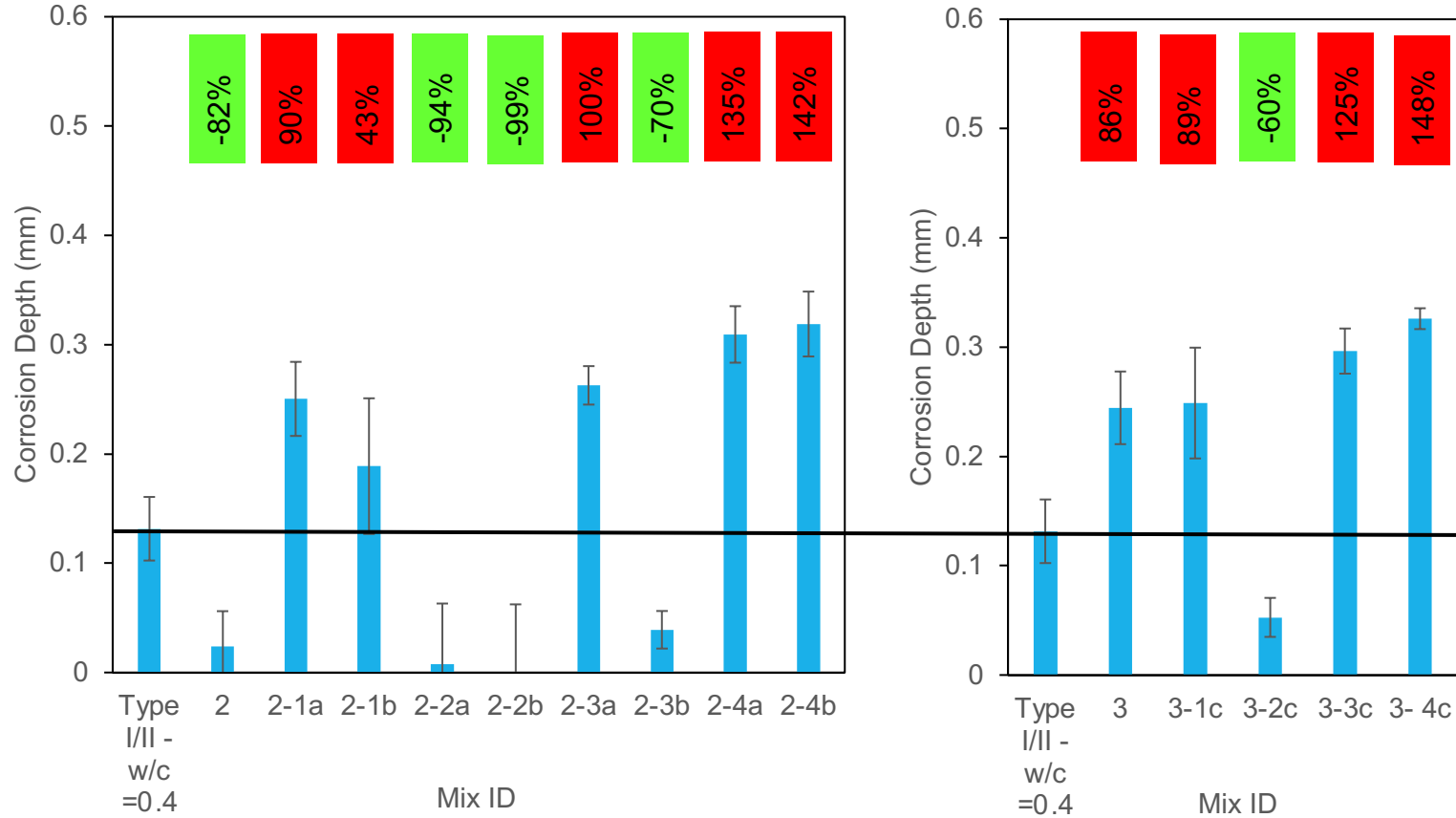
↑ = Selected for Further Study Based on Performance and Cost Considerations



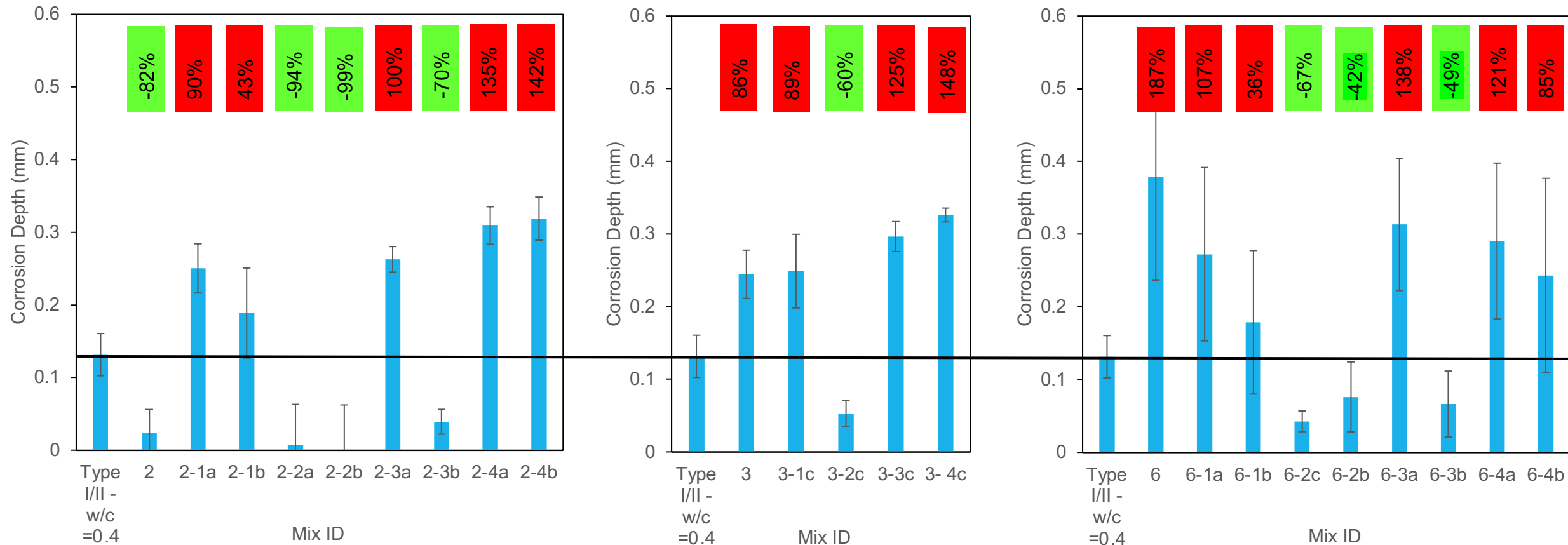
Results: Improved Sulfuric Acid Resistance



Results: Improved Sulfuric Acid Resistance



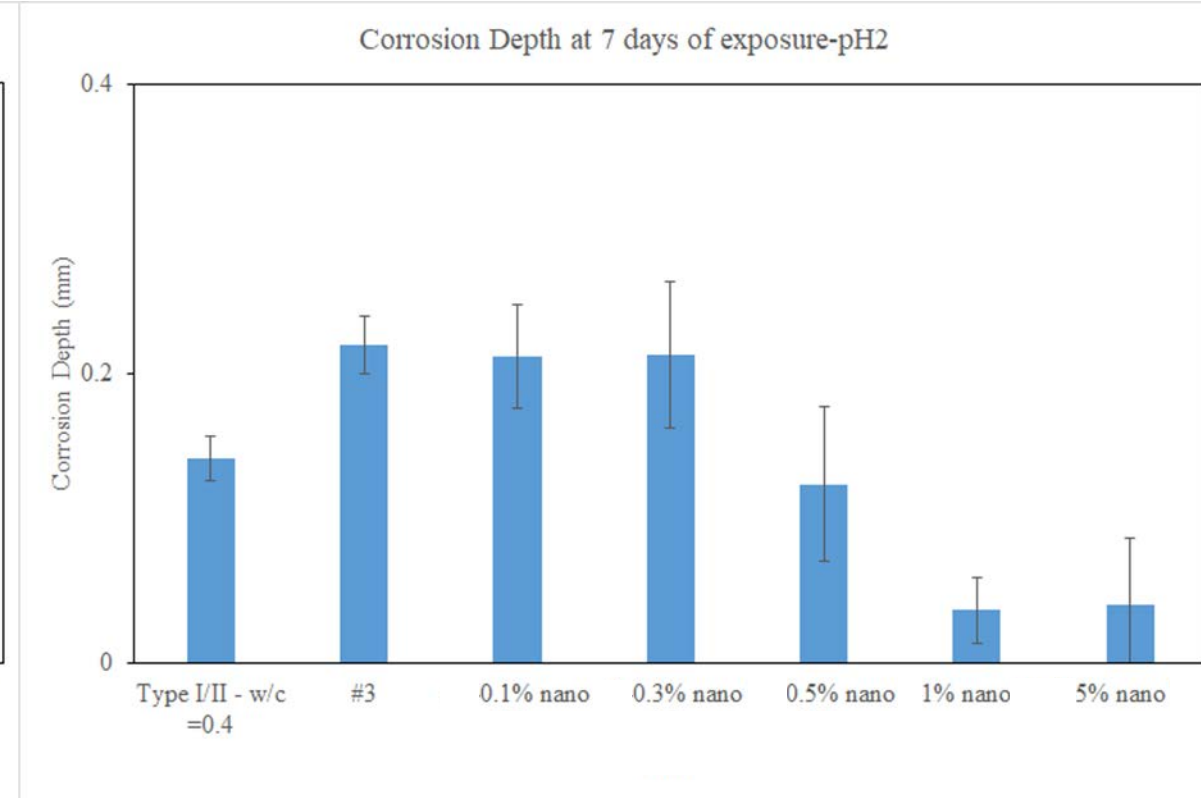
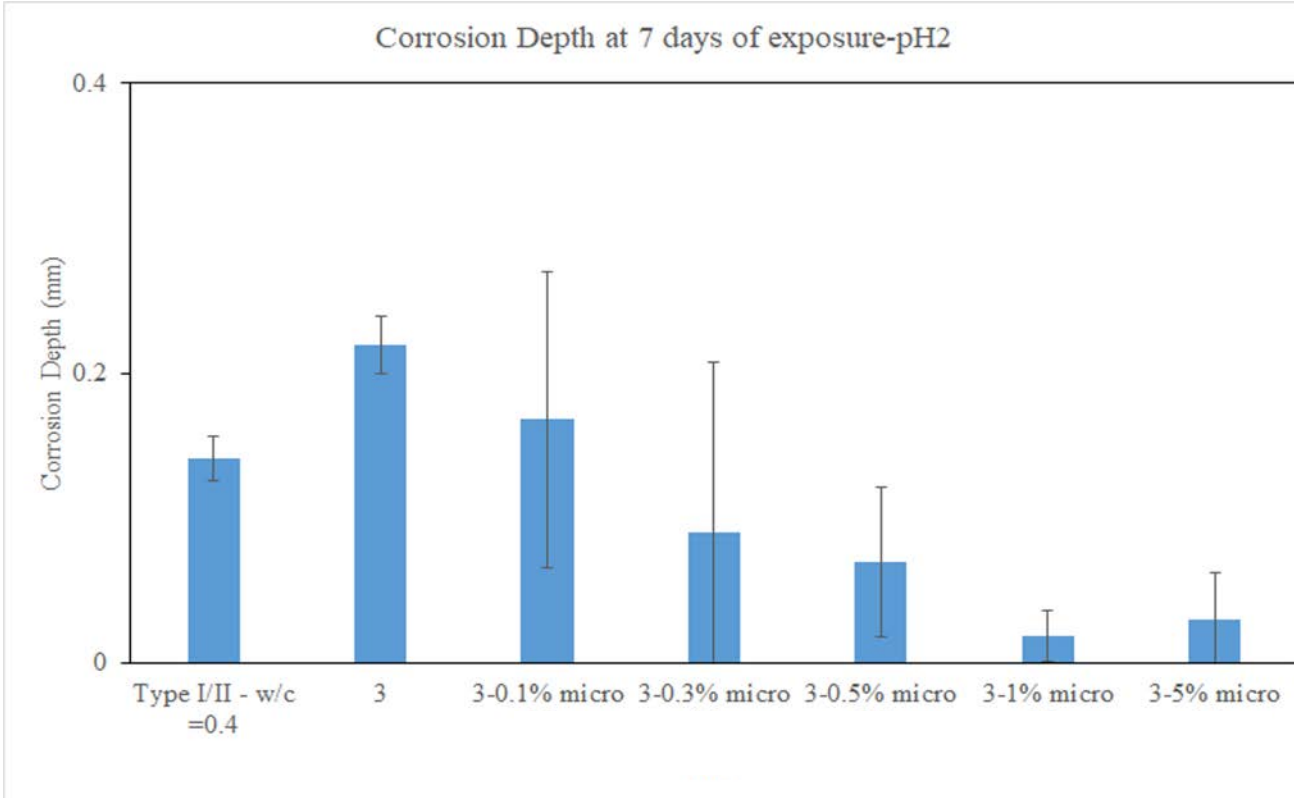
Results: Improved Sulfuric Acid Resistance



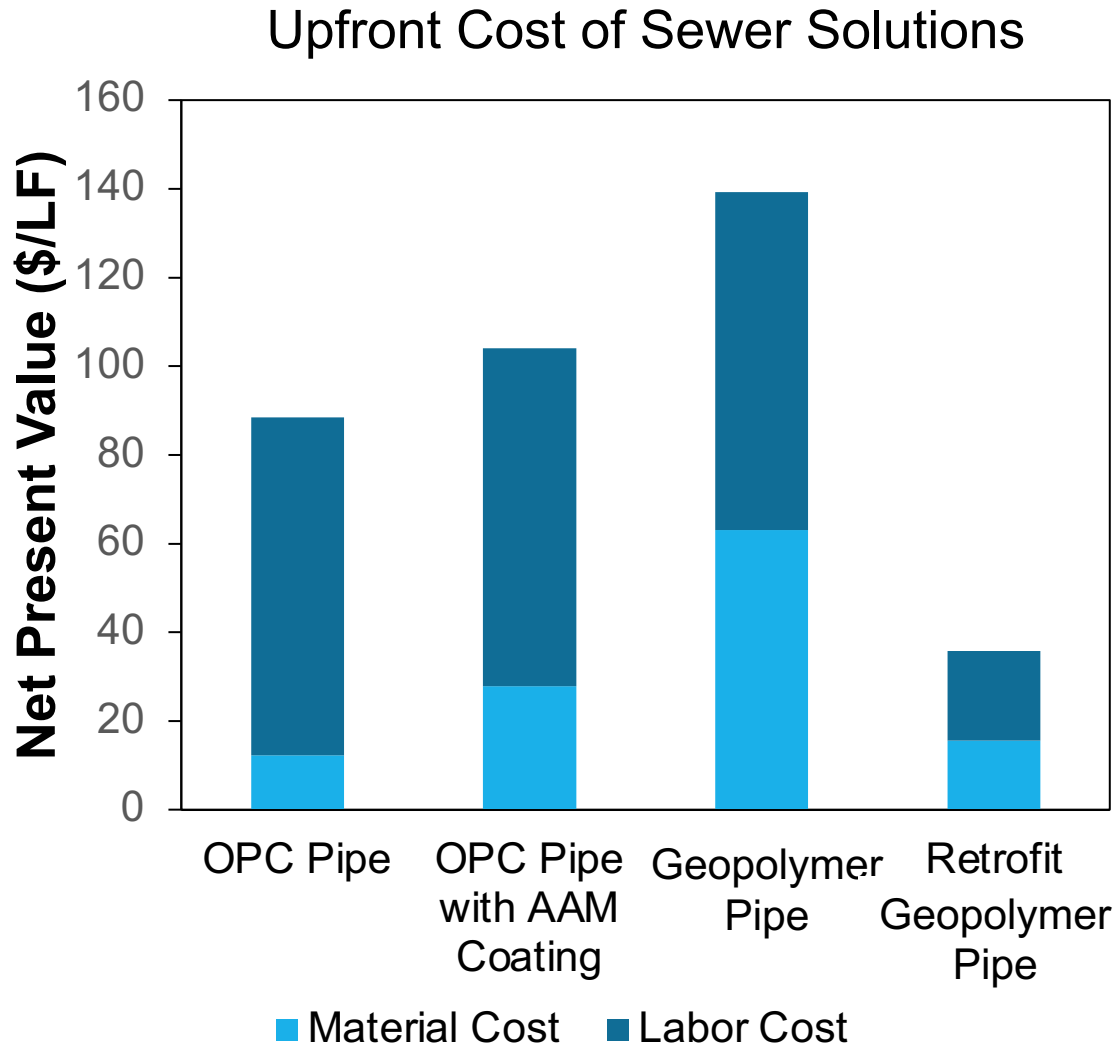
Main Takeaway: Geopolymer Mix #2 + Cation #2
Reduction = 94-99% (Original Goal = 80%)

Results: Improved Sulfuric Acid Resistance

Mix #3 with Cation #2

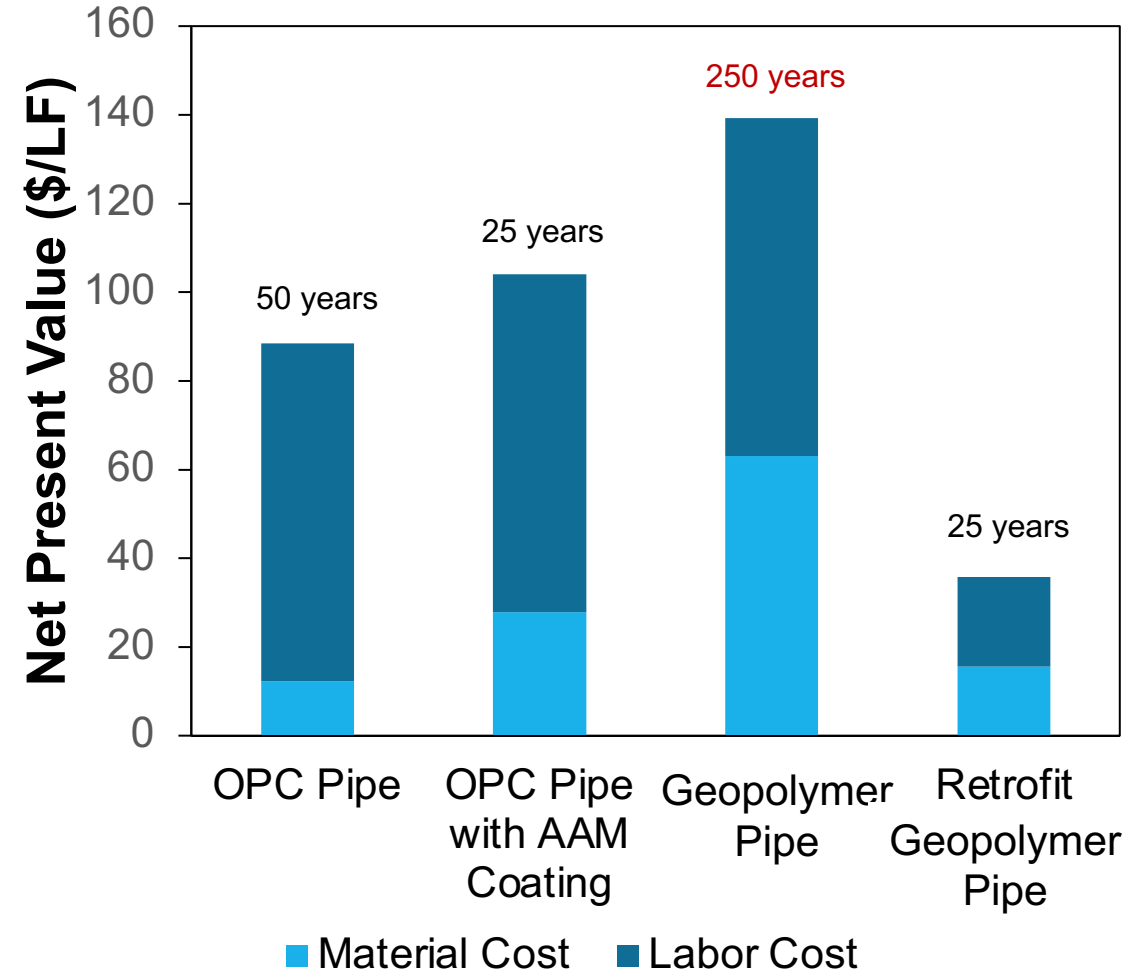


Results: Cost Analysis of Sewer Solutions

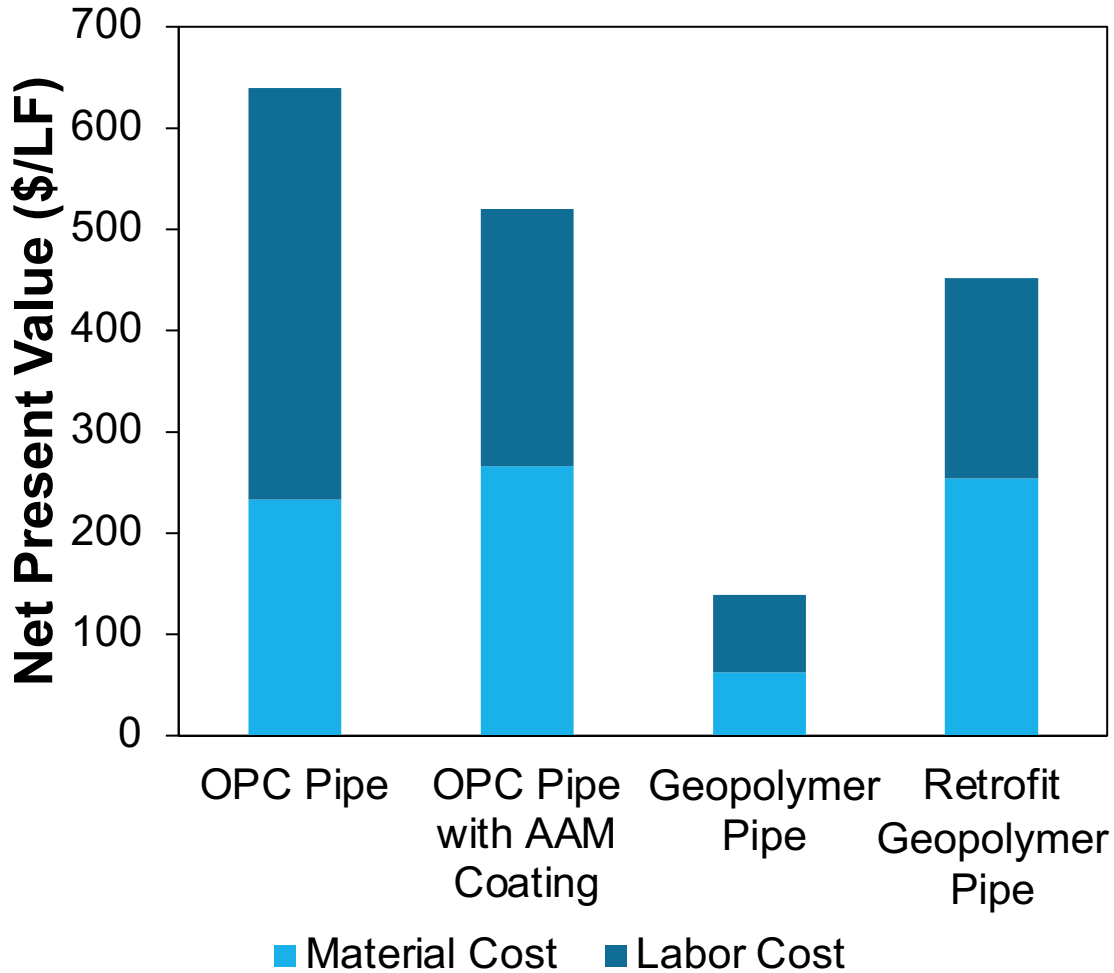


Results: Cost Analysis of Sewer Solutions

Upfront Cost of Sewer Solutions

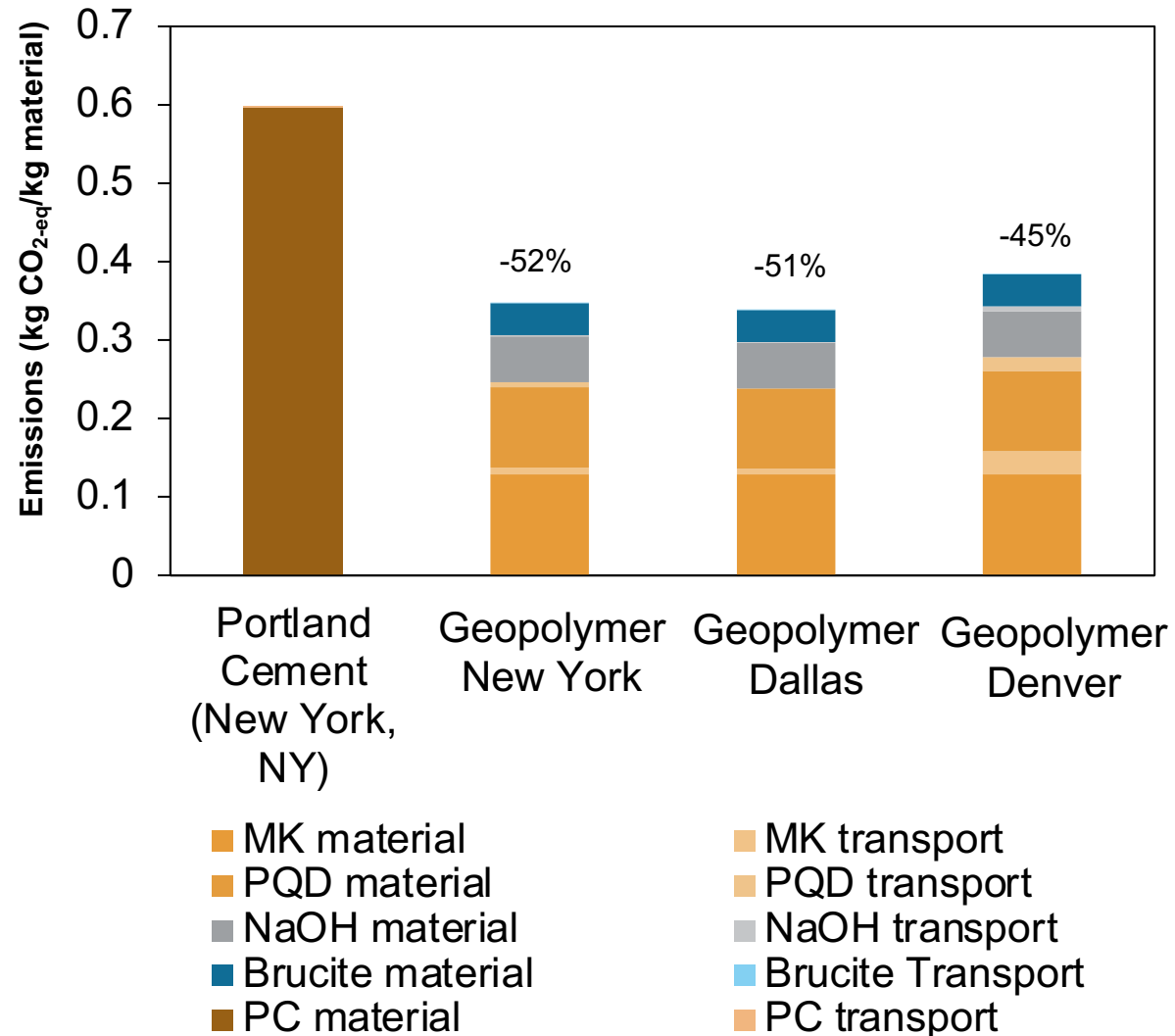


Net Present Cost of Sewer Solutions
(250 Life Span)



Results: Life Cycle Analysis Case Studies

Life Cycle Analysis: Case Studies



New York, NY Source Locations



We Are Actively Looking for Partnerships





University of Colorado
Boulder

Thank You!

Wil V. Srubar III, PhD, University of Colorado Boulder

Claire White, PhD, Princeton University

Mohammad Matar, Christine Pu, Xu Chen, Kai Gong, Yige Zhang, Halie Brimelow

Solving biogenic acid-induced concrete corrosion, cement-related CO₂ emissions, and life-cycle cost with performance-enhanced alkali-activated metakaolin (geopolymer) cements

wsrubar@colorado.edu